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SCIENCE & INDUSTRY

the place of Cambridge in any
scheme for their combination

The Rede Lecture 1917

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Director of the National Physical Laboratory

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SCIENCE AND INDUSTRY

For the past three years war and the consequences of war have dominated our thoughts, and compelled our actions. May we not hope now that the time is coming when we shall reap the fruits of the heroic efforts of those who have died that England might live. How can we best learn the lessons of this terrible time and turn the experience we have gained to the future welfare of our country? The question is much too wide and far-reaching to be dealt with in a single lecture, and it is beyond my powers to attempt to handle it in a general manner. I wish to deal only with one aspect.

We realized at a very early date that

science was to be an important factor in success, and while against the heroism of our men all that the science of our foes could do proved unavailing, it was clear that bravery and self-sacrifice without the aid which science could bring would fail to give us victory. Let me remind you of some few of the methods in which scientific investigation has aided our cause; they are so obvious as to need little more than a passing reference.

Take flying, for example, every part of a modern aeroplane is the product of a highly specialised science. In the machine itself, to combine strength with lightness, to select the right material for each part, to design the wings so that they may bear the greatest weight and offer the least resistance to the motion, to give the body ample strength to withstand the shocks of alighting and yet not weight the machine unduly—all these points

and many others have been the subject of long and difficult scientific examination.

At the National Physical Laboratory there are five wind channels continually in use to test on models all the various factors on which the aerodynamic efficiency of a machine depends. Two of these channels are 7 feet in diameter and nearly 80 feet in length; in one, wind speeds up to 60 miles an hour can be obtained. The model is attached to a specially designed balance or dynamometer and the forces it experiences in various positions relative to the wind are measured; from these data the behaviour of the machine in flight is determined. Here Mr Bairstow and his colleagues have worked out the practical conditions of stability of motion and determined by many ingenious devices the constants which occur in the theory. That theory was first given in a general form by

Bryan, the theory of the disturbed motion of a body moving in three dimensions, under gravity, the thrust of the propeller, and the resistance of the air. The quadratic which gives the energy in terms of the six coordinates and velocities corresponding to the six degrees of freedom of the body contains 21 constants. Conditions of symmetry reduce these in number, the air channel experiments afford the means for determining their values and thus predicting the properties of the machine. The work of Teddington would have proved of little value without the corresponding full scale experiments brilliantly carried out at Farnborough by two Cambridge men, E. H. Busk and Keith Lucas, who gave their lives for the cause, and now continued by two other Cambridge men, Farren and George Paget Thomson. The name of Busk is, I trust, to be commemorated in Cambridge by a scholarship

founded in his memory by friends who admired his powers and loved the man.

But it is not only in the structure of the aeroplane that science has done its part. The engine brought problems of the highest complexity, which are being solved by patient application and earnest endeavour. Large powers are needed ; the various parts move at great speed, hence strength is essential, but the weight must be kept down ; at the same time endurance is necessary ; risk of untimely failure must be reduced and the pilot made as secure as possible. ' Here the metallurgist has been at work producing alloys little heavier than aluminium yet comparable in strength with steel and suitable for many new demands, and in this field Dr Rosenhain, of the National Physical Laboratory, has arrived at most important results.

Or consider the instruments the pilot needs

to determine his height, his speed or the direction in which he is moving, to enable him to drop his bomb at the right moment, or to sight his gun on his enemy as the two planes come within range. Cambridge, as represented by Horace Darwin and Keith Lucas, has done yeoman service in these various fields, while in all our many discussions on theory we have profited by the great knowledge and the clear thinking of our Chancellor—Lord Rayleigh, President of the Advisory Committee for Aeronautics.

Again, turning to another subject, consider the science involved in the manufacture of a big gun and its ammunition, or in the calculation of the trajectory of its projectile. Many gun problems are not new: artillerists have long realised the importance of experiment and calculation, the manufacturer to test his steel and determine the safe stresses to which

it could be subject, the gunner to measure the resistance to the motion of the shell, to plot its trajectory, determine its time of flight for various ranges, set his fuse, and design his sights so that his shooting may be accurate. But the long range gunnery of our modern ships, the high angle fire required for anti-aircraft work, have each introduced new difficulties, and in solving these Cambridge men such as Littlewood, Hill, Richmond, Herman, Gallop and Fowler have been well to the fore, while for anti-aircraft work the Bennett heightfinder in one of its many forms is in general use in the Allied Armies.

One striking feature has been the development of methods of accurate workmanship. With some few exceptions all the gauges for munitions pass through the National Physical Laboratory. About 400,000 have been dealt with in the last eighteen or twenty months.

At first we were in despair. The limits of accuracy which the Inspection Department fixed were extremely narrow—in some cases only three ten-thousandths of an inch. Rejections were very numerous; to supply the requirements appeared impossible, but now gauges are examined at the rate of about 10,000 a week, and some 80 per cent. pass as a matter of course. Some firms get practically all their gauges through. Careful scientific examination of the causes of error, improved methods of manufacture and a firmer grasp of the essentials have produced this change; the standard of manufacture has been gradually improved, and results at first thought unattainable have been realised.

Physics and Engineering would afford many other instances, such as improvements in means of signalling, wireless telegraphy, sound ranging and weather prediction.

Chemistry and the Biological Sciences have contributed more than their full share, and though I cannot claim to speak with first hand knowledge of the achievements of medical science, I must mention some facts for which I am indebted to the kindness of Surgeon-General Sir Alfred Keogh and Colonel Webb, who informs me that the annual admission ratio for all causes other than wounds in action in France is approximately 428 per 1000. In the following campaigns the corresponding ratios were:

South Africa...	...	843
Nile, 1884-5 ...	...	557
Egypt, 1882 ...	...	2276
China, 1900-1 ...	...	933
Nile, 1898 ...	...	955
Dongola, 1896 ...	...	892

In France the annual admission ratio for typhoid fever is 0.9 per 1000, and for the whole typhoid group of diseases 2.4 per 1000.

In South Africa the annual admission ratio for enteric fever was 130 per 1000, and for enteric fever plus other continued fevers 204 per 1000.

The figures speak eloquently of the triumphs of Medicine, and the wonderful results achieved by the devotion of doctors and nurses.

Many of those present have no doubt seen the collection of essays called *Science and the Nation*, recently issued from the University Press. Let me refer to Prof. T. B. Wood's essay "An Agricultural War Problem," or to that by Prof. Biffen "Systematized Plant Breeding" to illustrate the work which has recently been done here by scientific men for agriculture and food production. Professor Wood deals with a problem presented by the President of the Board of Agriculture in 1915 "How to buy Feeding Stuffs for

Cattle to the best advantage, and how to use them when bought." I must refer you to the book itself for the solution. From Prof. Biffen's paper we learn how improvements of enormous value have been effected in wheat suitable for growing in England.

The war has brought home to us, in a way that only an event of its magnitude can do, the dependence of the modern world on science and the advancement of natural knowledge: the need then is that when peace comes we should use this great power to the full to repair the ravages of war.

A recent number of the *Times Literary Supplement* contained an interesting comparison between the forces at work in moulding the world now and in the first century of our era. It took the form of a review of Mr P. E. Matheson's edition of the works of Epictetus, and in it the author writes "How much, for

instance, of the command over the realm of matter characteristic of modern industrial enterprise is due to the pure scientific interest of individual investigators, the interest which is the pursuit of truth, subjection of the spirit to Universal law, asceticism which suppresses every impulse that might interfere with dispassionate verification. It is an obvious confusion of thought to call western civilisation materialistic because it deals with material masses. It is a creation of the human spirit. Every faculty of the spirit has gone to the making of it—desire, imagination, character, will. Because in making it the human spirit has been largely occupied with acquiring command over matter it has in many persons lost the sense of other things, has become concentrated upon some lower end, has worked for commercial gain or power for power's sake. Yet may be questioned whether our modern

civilisation could go on at all—still more whether it could continue to advance in knowledge—unless there were intermingled in its governing interests those which belong to the human spirit at its highest, those which seek to acquire command over matter only in order that they may use it for spiritual ends. Our modern ‘western’ civilisation has enormously increased the content and potentialities of life, and like all increases of resources and power has made it harder to enter the Kingdom of God. Yet, just because the problem set the soul is more complex, because its solution is harder to attain than the simple detachment of Epictetus or an Eastern sage, it yields, if attained, a richer result.” And if, as I think, this is true may not we in Cambridge while we endeavour so to advance knowledge as to place the forces of nature more completely at the service of man, strive

that the world should realise that the highest object of this command of matter is to use it for spiritual ends. The great Cambridge physicists who have left us within the memory of many here present—Adams and Cayley, Stokes, Maxwell, and Kelvin—realised this; the desire to discover the truth, to advance knowledge for its own sake, lay at the root of their endeavours and was the cause of their success.

A distinction is often drawn nowadays between pure science and industrial science. I saw somewhere recently a protest against the use of the latter term. Science is one, and industrial science—so-called—is the application of the discoveries of pure science to the problems of industry. Huxley wrote long ago:—"What people called Applied Science is nothing but the application of Pure Science to particular problems." It is essential that we should

remember this, and strive here in the first place for the advancement of Pure Science.

Scientific investigations we may divide into two classes. Those in pure science which are directed solely to the advancement of natural knowledge, the discovery of Nature's laws; and those which have for their aim the application of these discoveries to the processes of our everyday life in art, or commerce, or manufacture. There is no need to lay stress in this room on the paramount importance of the first class. The Cavendish Professor, speaking recently in London, said truly "the discoveries in applied science may produce a reformation, those in pure science lead to revolutions."

The book *Science and the Nation*, to which I have already referred, written, according to the preface of the Master of Downing, to enable the reader to grasp in its true perspec-

tive the relation of pure science to applied science,—“the worker in pure science discovers, his fellow in applied science utilises,”—teems with illustrations: let me remind you of one or two.

Faraday, when he succeeded in making a wire carrying a current move when in a magnetic field, had no thought of the applications of electro-magnetism to-day, and the question of a visitor, “Tell me, Professor Faraday, and of what use is this new discovery,” led to the well-known answer, “Sir, of what use is the new-born child?”

✓ The Röntgen rays, as Professor Thomson has recently pointed out, were studied first as one means whereby we might hope to learn something of the nature of electricity. They are now the surgeon’s trusted guide, telling him how to direct his knife and restore his patient to health and strength. Pasteur’s

work commenced in an enquiry into the crystallographic differences of certain chemical substances, leading him to the result that certain kinds of chemical fermentation are due to the action of living organisms which are not born spontaneously in the fermenting material but are derived from infection. Lister seized on this and applied it to medicine and surgery. The medical statistics of the war will shew, when they can be prepared, something of what the world owes, measured in lives saved for future work, to these two discoveries; the amount of pain the sufferers have been spared is immeasurable.

Lord Moulton, in his preface to the book, refers with special pleasure to Dr Rosenhain's essay on Modern Metallurgy. The foundation of this work rests on Sorby's application of the methods of petrographic research to investigate the properties of meteorites, and on the

study of the thermoelectric properties of metals due to Seebeck, Peltier, and William Thomson. Petrographers had been in the habit of examining the structure of rocks by cutting sections thin enough to be transparent and examining them under the microscope. Sorby in 1861 found it was not possible to examine metals thus and developed the art of polishing the surface and etching it with suitable chemicals, thus bringing out the internal structure. Its application to engineering problems passed unnoticed until the method was independently revived by Osmond in France and Martens in Germany. Seebeck discovered that when in a circuit of two metals a difference of temperature exists between the junctions, an electric current is produced in the circuit. The strength of this current is a measure of the difference in temperature, and this discovery was applied many

years later by Le Chatelier to construct a thermocouple for the measurement of temperature in metallurgical processes. Applying these two instruments of research, metallurgists have now a clear idea of the structure of the more important metals and alloys used in industry and of the manner in which the properties which fit them for their various uses are related to that structure. The intensive study of pure science, the determined effort to hand on still brightly burning the lamp lighted for us by those who have gone, is perhaps the best contribution which Cambridge now can make to our national welfare.

“Science,” writes Professor Bragg, “grows like a tree which shoots out new branches continually and at the same time strengthens the old; twigs become boughs and the boughs become great stems, while the tree is ever growing upwards towards the light and more

firmly based below. Science is like a tree also in this that both need wise cultivation. The nourishment of the tree, its training and pruning, have their counterparts in the development of science; in both cases the fruit comes as the reward of skill and labour. This is the thing which is hard to understand and yet is so important." This is the fact which it is essential for Cambridge to grasp and to impress upon the Nation.

The great discovery is usually small in its beginnings, it does not at first strike the imagination. The seeds from which the revolution is to come lie hidden in the ground, and the tiny sprout which first appears seems but of small importance.' Few besides some students in the Universities realised the wide-reaching scope of Maxwell's theory of the electromagnetic field, when it was first published; few again pictured, when they read

of the early experiments of Hertz and Lodge, the future marvels of Wireless Telegraphy, even in the short years that have passed since Lodge delivered his Royal Institution lecture. The successful applications of science to industry attract a wider notice and gain a fuller recognition. It is given to but few men to carry through the revolution that their own discoveries have produced. James Watt and Kelvin were such men. Pasteur and Lister saw, in some degree, the fruit of their labours. Faraday, on the other hand, died at Hampton Court in the receipt of a civil list pension. The work of making the discoveries of science available to promote the prosperity and advancement of a nation appeals to others than the great discoverers and is usually best left in other hands. Let me explain what I mean, even at the risk of some repetition, for I have recently spoken and

written more than once on this subject, and indeed the applications of science to industry have been the work of the National Physical Laboratory since the twentieth century began.

Speaking at the opening of the Laboratory in 1902, His Majesty—then Prince of Wales—said: “The object of the scheme is, I understand, to bring scientific knowledge to bear practically upon our everyday industrial and commercial life, to break down the barrier between theory and practice, to effect a union between science and commerce,” and these words still express our aims.

Various writers have pointed out recently that in this process three distinct stages are generally required. We need

- (1) The work of the man of science in his Laboratory;
- (2) The investigations which go on in a Laboratory of Industrial Research,

developing new processes or introducing new products ;

- (3) The Works Laboratory proper, controlling the quality of raw materials, or of finished products.

I have spoken already of the work of the student of science in his University or College ; before dealing with the Laboratory of Industrial Research let me devote a few words to the Works Laboratory proper.

It is necessary, as I have said elsewhere, to maintain the standard of the output, to secure that the proper grade of material is supplied to the works, to check the instruments in use, and to test the product in its various stages of manufacture. ✓ The days are gone when successful manufacture could be carried on entirely by rule of thumb, trusting to the skill of some trained workman for the success of each delicate operation,

when the hereditary instinct passed down from father to son was sufficient to produce each year practically the same results. New processes come, which appear likely to improve production or to reduce its cost; the Works Laboratory serves to test these. New products are suggested, which may or may not have the advantages claimed for them; this can be investigated in the Works Laboratory, and all these investigations and tests must go on in the works themselves under the eyes of men familiar with the process of manufacture in its every stage.

A distinguished Trinity man, Mr Michael Longridge, when recently addressing the Institution of Mechanical Engineers, as their President, he traced the process by which during the latter half of last century England became the leading industrial nation, concluded thus:—

“And as the mechanical engineer was responsible in no small measure for the transformation, so he must be held responsible for the maintenance and efficiency of the workshop on which the feeding of the people and the defence of the people against their enemies now depend. He became and he remains a trustee of the British Empire. How did he discharge the trust? By humbly seeking knowledge to turn the gifts of Nature to the use of man? By invoking the aid of science to develop the discoveries of the men who had prepared the road to his success? By caring for the welfare of the thousands who were spending their waking hours in his factories? By giving them a fair share of the profits of his business? I think we have the grace to-day to answer NO. I think we are willing to confess that our heads were turned by elation at our prosperity, that we were obsessed by admira-

tion of our own achievements; too confident of the sufficiency of our limited knowledge; too contemptuous of the few who tried to throw the light of science on our path; too eager for wealth, and the social influence it could buy in the new state of society; too careless of the needs and aspirations of the 'hands' who helped to make the rapid accumulation of large fortunes possible.

And what has been the consequence? For every lapse from the ideal, and there is an ideal even of industrial polity, Nemesis Adrasteia, sooner or later, exacts retribution."

The lesson has now been learnt with more or less completeness, and to-day each modern engineering works possesses its own laboratory and utilises the teaching of science at each stage of its processes. Cambridge can supply the men who will do this work. To this question I hope to return later.

But there is another need. The step between the University laboratory and the Works laboratory is a long one. Discoveries do not leave the man of science in a form which can be at once assimilated by the engineer, the shipbuilder, or the manufacturer. Some means are needed to make them available to such men, to secure for them the advantages which come from the growth of knowledge by which alone they may keep in the forefront of their trade. The problem has recently been discussed in a paper by Dr Mees published by the Department of Scientific and Industrial Research, and by Dr Rosenhain in a lecture, delivered at Glasgow, on "The National Physical Laboratory—Its work and aims." Dr Mees writes:—"This kind of research work involves a laboratory very different from the ordinary works laboratory, and also investigations of a different type from those employed

in a purely industrial laboratory. It means a large elaborately equipped and heavily staffed laboratory engaged largely in work which for many years will be unremunerative, and which for a considerable time after its foundation will obtain no results which can be applied by the manufacturer." While Dr Rosenhain in the lecture already referred to takes as an instance the case of a series of alloys which is being studied by an investigator interested mainly in theoretical metallurgy ; he works with pure metals or metals as nearly pure as he can get them, and finds that one alloy of his series has some specially noteworthy properties. He may call the attention of a manufacturer to these and suggest that the alloy might have valuable industrial application. Much, however, remains to be done before this can be realized ; the pure materials of the investigator are not available in

quantity. To what extent is the presence of impurity detrimental, what are the impurities which must be removed, what are the steps required to do this on the requisite scale, to what extent do the difficulties involved in this render the whole method commercially impossible by adding seriously to the cost? Is there any difference between the material made in quantity and that produced by the laboratory furnace, where rapid cooling or heating may be readily employed, although impossible in the full scale work, and so on? For the industrial research laboratory the plant, etc., must be so planned that it is possible to carry out the necessary operations on a scale comparable with that required in works, and, moreover, the man who carries through the investigation must be not only acquainted with the latest scientific advances in his subject, but must know what is possible

in works, and must mould his solution of the problem to harmonise with these possibilities. The undertaking is often more complex than that of the pure scientist. It is one which needs a special laboratory, a special equipment.

As examples of such a laboratory, both of which happen to be at works, I may instance the Research Laboratory of the Badische-Anilin-Soda-Fabrik, in which the commercial production of synthetic indigo was worked out, or the laboratory of the General Electric Co. of America at Schenectady, where in numerous instances the discoveries of modern electrical theory have been turned to practical use. The Coolidge tube, the most powerful source of X-rays which we possess, is one product of this laboratory. Other examples are some branches of the Bureau of Standards at Washington, the Materialprüfungsamt at Gross-Lichter-

felde, near Berlin, and, in some aspects of its work, the National Physical Laboratory and the Research Institutions for Glass, Pottery, Fuel, etc., which are coming into existence as part of the work of the Department of Scientific and Industrial Research.

Thus, the task of an institution like the National Physical Laboratory differs from that of either a University or Technical College Laboratory or a Works Laboratory. In the first place it is not educational; every member of the staff is, it is true, learning continually, but he is not there to be taught, but to be asked questions and to find the answers. Its functions are primarily to encourage and initiate the applications of science to the problems of industry. It is, in the words of the Order in Council establishing the Research Department, an institution for the scientific study of problems affecting particular industries and trades.

The staff devote themselves solely to this work, their whole time and energy are given to it. They have no educational duties, they are free from the responsibilities of the class room and the burden of students' exercises. The senior members of the staff joined avowedly with the purpose of applying science to industry; they are prepared to make it their life-work. The juniors retain their posts for some time; thus all acquire a store of experience of the highest value, with a unique knowledge of the technical aspects of industry which it is difficult to gain in any other way. The Laboratory has, I trust, acquired the confidence of the technical industrial world, and problems are brought before the staff with the knowledge that they will be handled in a confidential manner by men trained to deal with them. In such an institution it is possible to specialise as to both staff and equipment

in a manner which can hardly be done in a laboratory attached to an educational institution. The whole staff are engaged in applying science to industry; equipment is provided for this purpose only.) The needs of the student and the educational value of the apparatus have not to be considered.

I would not advocate that work such as I have outlined should, as a rule, find a place in a University laboratory, but a University has its own task in connection with these laboratories which, believe me, are a necessity if science is to be freely applied to industry. The Universities and Technical Schools must provide and train the staff, not in the applications of science, but in methods of investigation, in the knowledge of scientific truths, in the power of observation, the capacity to interpret the observations they make and the experimental results they obtain, and, above

all, in the desire to discover the truth and apply the consequences fearlessly to their daily work.

Nor is this all. No doubt the number of men engaged in the application of science to industry must increase, but if we are to reap the full advantages science can give, steps must be taken to ensure a wider appreciation of the value of her gifts, the greatness of her powers.

Some knowledge of the meaning of ordinary scientific terms, of the usual everyday processes of Nature—both chemical and biological, of the cause of the simple natural phenomena, and of the general scope and methods of scientific enquiry should be the possession of each undergraduate before he leaves Cambridge to take up his life work elsewhere. "It is essential," as Professor Keeble writes in his contribution to the essays

already frequently referred to, "that our statesmen and administrators, our teachers and our poets, know something of the work and method and beauty of science," but how is this to be secured? Mr Wells, in a recent review of the Essays, is severely critical because the authors have not answered this question: the criticism is undeserved, it seems to me, because the authors did not set out with this object. "The time seemed propitious," says the Editor, Dr Seward, "for emphasizing a particular aspect of the general question of the inter-dependence of many phases of national prosperity and a just appreciation of the value of pure science." Still, the question needs an answer. We look forward with some eagerness to the report of the Committee, of which Sir J. J. Thomson is chairman, which is dealing with the place of Science in Education.

Meanwhile, it may not be out of place to hazard some few remarks. I will quote again from the President of the Institution of Mechanical Engineers, who, after pointing out that the education of an engineer must be varied to suit the capacities of different minds, writes thus:—

“And my complaint. It is against the obstinacy of our two most famous Universities in retaining Greek as a compulsory subject in their examinations. This reacts upon our public schools, and is a serious handicap on those who, intending to deal with the concrete rather than the abstract in their future lives, yet wish to find their levels in the social life and moral discipline of these two Universities. The English public school boy can generally be relied on to face difficulties, lead men, and keep his hands clean in business. Engineering cannot afford to lose him to satisfy those

who rule Oxford and Cambridge in this matter."

To insist on the retention of Greek in the Previous Examination is to close Cambridge to many of those who would profit most by its lessons, who would carry the rich benefits three years residence here can give to places where at present they never penetrate, and who themselves in not a few instances would add to the lustre and the glory of our University.

The study of Greek is not really advanced by its compulsory character. Lord Bryce, in a recent article addressed in the first instance to a classical audience, writes, after a reference to the very few who retain a competent knowledge of Latin and Greek beyond an early age:—"Let us frankly admit the facts. Let us recognise that the despotism of a purely grammatical study of the Ancient

Languages needed to be overthrown," and he continues: "What is the chief aim of education? How should the mental training fitted to produce the capacities which go to make an educated man begin? First of all by teaching him how to observe and by making him enjoy the power of observation. The attention of the child should from the earliest years be directed to external nature. His observation should be alert and it should be exact. Along with this he should know how to use language, to know the precise difference between the meanings of various words apparently similar, to be able to convey accurately what he wishes to say." Then, after distinguishing between the world of Nature and that of man, he discusses how the time available for education is to be divided between these two spheres, urging the need for plenty of knowledge of both to produce a capable and highly finished

mind. "No man," he says, "in our day can be deemed educated who has not some knowledge of the relation of the sciences to one another and a just conception of the methods by which they respectively advance." He presses strongly the importance of literary studies because of the service they render to us for practical life, for mental stimulus and training, and for enjoyment, and as an introduction to his views on the claims of the classics, he writes: "A word must be said on the practical aspect of the matter as it affects the curricula of schools and universities. I do not contend that the study of the ancients is to be imposed on all, or even on the bulk, of those who remain at school until eighteen or on most of those who enter a university. It is generally admitted that at the universities the present system cannot be maintained—we shall effect a saving if we drop the

study of the Ancient Languages in the case of those who after a trial show no aptitude for them. For the schools, the problem is how to discover among the boys and girls those who have the kind of gift which makes it worth while to take them out of the mass and give them due facilities for pursuing their studies at the higher secondary schools so that they may proceed thence to the universities and further prosecute them there. Many of you, as leaders, know better than I how this problem may be solved: solved it must be if the whole community is not to lose the benefit of our system of graded schools." And in this connection let me quote a few words from a recent letter in *Nature* by Mr M. D. Hill, an Eton master of 20 years' experience. He writes: "The boys who are best at classics are also best at science....Every intelligent boy must be given equal oppor-

tunities in science and languages in the widest sense of the word until he is old enough to show which line of study he can most profitably follow."

Here is a problem which the University must attack at once. I have already pointed out what seems to me the first step towards its solution. Cambridge must open her doors wide to every son of our great Empire who can show that he will reap benefits from studying within her walls any branch of knowledge for which she offers opportunities: this step should be taken without delay. Lord Bryce has indicated, I think, the lines for our future development: let me briefly outline how they appear to me to run. The University must remain the home of Ancient Learning, but the course pursued to secure this end must not be such as to demand that Latin and Greek should remain the principal part of the school

tasks of all boys. It must train men to be leaders in all walks of life, and not least in industrial pursuits, and this not by undertaking the technical training of the men who go out hence into the world but by laying a broad foundation of the scientific principles and laws on which technical knowledge, be it of theology, medicine, or law, or of the more modern branches of applied science, must rest. And lastly, but most important of all, it must produce the leaders in every branch of science. To develop the steps by which all this is done is a task far beyond me; I do not propose to attempt it.

For the highest work of all, be it literary or scientific, the course is fairly simple. Men in whom are implanted the thirst for new knowledge, the power of discovery, the keen logical insight to follow the right path and avoid the wrong, will come to the front helped

by the traditions of the past, the enthusiasm and devotion of our teachers, the generosity of our founders and benefactors. Funds, it is true, will be needed and must be supplied. A man whose researches may produce a beneficial revolution, whose discoveries may prove of untold benefit to mankind, should not depend for a scanty livelihood on the proceeds derived from his yearly cycle of tutorial lectures. Means must be found to increase the endowments of the University for pure research, and funds so expended will in time produce a full harvest.

Let me, however, endeavour to say something as to the steps to be taken to give science its due place in the education of every man. Have we attacked this question in the right manner, and by we I mean teachers of science generally?

It is nearly 40 years since the present

Chancellor asked Sir Napier Shaw and myself to help in his work at the Cavendish Laboratory. Practical Physics as a branch of study for undergraduates generally was almost non-existent. Maxwell had inspired a few of the leading mathematicians with the desire to work at the Laboratory, but the organised classes were small and their organisation was incomplete. Elsewhere, Carey Foster had classes at University College, Balfour Stewart at Manchester; Kohlrausch's book had been published and translated into English some few years previously. Shaw had worked in Berlin under Helmholtz. We commenced the endeavour to systematize the teaching, to devise experiments to illustrate and "prove" fundamental laws and principles, to teach students the reality of many things of which they read in books and shew them that effects do follow their causes in the manner there

described. Principal Griffiths, in a recent lecture, recounts a Cambridge experience. He had been explaining to some pupils the laws of floating bodies and asked one of them to come to his laboratory in the afternoon and verify what he had been told. The man looked up with mild surprise and asked, "Do you mean to say this really comes off?" Teaching by experiment was clearly necessary.

Laboratory notebooks were written. In due course (in 1885) Glazebrook and Shaw's *Practical Physics* appeared, and I am glad to say after over 30 years of life is vigorous still. It has been followed by many similar books and has, I trust and believe, done much useful and important work. A man who is to develop into a physicist must have an intimate knowledge of the existing methods of physical investigation. Measurement is so important a factor in many branches of knowledge that

an acquaintance with the fundamental methods of measurement, and skill in using instruments and apparatus, are of the highest value for large classes of men.

But for the great majority the mental food thus offered affords but little nourishment. The teaching of Practical Physics on these lines fits in with our examination system. Problems can be set and questions asked admitting of definite and precise answers whose value an examiner can easily assess in marks. A sum in arithmetic is classed as a physical problem because the term "specific heat" or "electrical resistance" is used in stating the question. "Our examination system," says Principal Griffiths, "has endeavoured (but, thank heaven, unsuccessfully) to kill the soul of Science in the rising generation. There is, however, a stirring among the dry-bones and we are awakening to the fact

that Science must be taught as if we believed in it for its own sake, that we must preach it as a disciple preaches his religion, and that we must refuse to be bound by the fetters in which tradition has entangled us. If we are to succeed, we must make science a living reality to our pupils and cease to regard it merely as a convenient machinery for the manufacture of conundrums." We do not really so regard it, any of us teachers, but our methods of teaching and examinations tend to produce this impression. My very intimate friend and colleague of the past 45 years has put the matter, when writing recently to Sir J. J. Thomson, in more vigorous language, perhaps, than I should use. He says, "I know partly how it has come about, because really I had a hand in it myself. What was meant as an expedient to keep a class of boys usefully occupied with a limited stock of

apparatus has now become a monstrous growth, a malignant disease of the educational system." Or again, in more moderate words, "When we come to consider such provision as there is for science in general education, as represented by the opportunities actually offered to boys and girls at school, it is for me impossible to avoid the conclusion that what the exponents of physical science have evolved as the elements of scientific education is quite unworthy of the subjects we desire to expound." In the hopes that the error may be retrieved I, like him, wish to express my repentance for my share in it and appeal for a reconsideration of the position to those whose duty it is to determine the form in which a general education in science is in future to take. It is clear, I think, that a plan which is excellent for men who intend to specialise in science is not the one best suited to give to

all—"some knowledge of the relation of the sciences to one another and a just conception of the means by which they advance." For the limited class an exact knowledge of the elements is essential. If this exact knowledge is required from all, the majority find the process dull, they get no further than the elements, and when the dreaded examination is over they forget even these and have no further interest in the subject. Natural Science, like Latin and Greek, disappears from their lives.

And so, if this be at all the correct view, an important task for the University is to develop a new method for the ordinary teaching of Science, not merely to require that Science should be taught but to discuss and determine how this can best be done, and then to train and send out into the world men capable of doing it. The method will not

lend itself easily to "the process of controlling education by examination with a limited time," and if a test of the pupil's knowledge is required, some other plan for this purpose must be devised.

One of the consequences of the war will be a greater appreciation of the value of science. Let us in Cambridge be ready to take advantage of this and help to strengthen our country by raising up a generation which realizes to some extent what science has done and how real progress in nearly every walk of life is inseparably bound up with the advancement of Natural Knowledge, which in the past this University has done so much to promote.

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